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ANALYSIS OF EXPOSURE TO ELECTROMAGNETIC FIELDS IN A HEALTHCARE ENVIRONMENT: SIMULATION AND EXPERIMENTAL STUDY

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ANALYSIS OF EXPOSURE TO ELECTROMAGNETIC FIELDS IN A HEALTHCARE ENVIRONMENT: SIMULATION AND EXPERIMENTAL STUDY

Silvia de Miguel*, Miguel Angel Martín**, Alejandro Del Pozo*, Victor Febles**, José A. Hernández**, José C. Fernández de Aldecoa**, Victoria Ramos*

Abstract – Recent advances in wireless technologies have produced an increase in wireless instrumentation present in healthcare centers. This paper analyzes the signals of the different wireless communications systems in the Canary University Hospital Consortium (CUHC), in order to evaluate the electromagnetic (EM) conditions. The results of the assessment are represented through 2D contour maps.

The electromagnetic conditions detected with the experimental measures have been estimated with the software "EFC-400 Telecommunication", commercialized by Narda Safety Test Solutions. This tool allows the simulation of real healthcare environment conditions considered in this study.

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KEYWORDS: exposure; radiofrequency; electromagnetic fields; environmental assessment; radiation protection.

INTRODUCTION

A large hospital currently presents a great variety of wireless telecommunications systems that generate electromagnetic (EM) fields with different features and intensities. These systems range from medical equipment with telemetry systems to the usual wireless communication systems, such as healthcare professional tracking devices (pagers), terrestrial trunked radio (TETRA), digital enhanced

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cordless telecommunications (DECT), wireless local area networks (WLAN), and conventional mobile phones (Carranza 2011).

An important issue to consider when a new wireless system or a new electrical device is being installed in a healthcare center is to identify the main radiation sources and predict the intensity of the EM fields. A high level signal can compromise the safety conditions of people in hospitals, and can affect the proper working of the communication systems and the sensitive medical devices (Tang et al. 2009, Hietanen and Sibakov 2007). The safety in hospitals must be compatible with the requirements of coverage and quality of service of the communication systems and the sensitive medical devices.

There are two aspects that should be analyzed and considered to assure a proper, reliable and safe usage of the wireless communication technologies and medical equipment in healthcare environments. The first is the compatibility and possible interferences between the different types of signals, which share the same transmission band (Betta et al. 2008). The second is the compliance with exposure level thresholds (DEPC 2004; DEPC 2008), to quantify and analyze the risk of continued exposure caused by the use of wireless technologies (Carranza et al. 2009, Carranza et al. 2011). Due to the potential health effects of EM radiation, various studies delve into the consequences of the exposure to wireless communication devices (Zygiridis and Tsiboukis 2008, Hirata et al. 2009).

On the other hand, the contribution of certain medical devices must also be considered. Medical devices can generate EM fields that disrupt the radio environment of hospital areas where they are located. It is also possible that in certain areas of the healthcare center, high frequency signals are detected as a result of pollution caused by broadcast commercial radio stations or communications systems that use commonly used frequency bands (walkie-talkies, radio ham or broadcast of security forces and civil protection), in addition to those received by mobile operator base stations (MEE 2008; Ramos et al. 2008).

Nowadays a considerable range of wireless communication networks of commercial purpose coexist with an increasing number of sensor networks and personal medical devices in healthcare environments. These devices work in wireless channels and are vulnerable to malicious attacks, as a result, medical records or diagnostic images could be intercepted, harming the health and the confidentiality of the patient (Malasari and Wang 2009). The study of EM conditions in the range of personal communication frequencies assures the proper and secure working of implantable devices and sensor networks, avoiding malfunction (Morrissey at al. 2002, Calcagnini et al. 2006).

Large hospitals, especially if they are not new, generally consist of several old buildings of different nature and constructive characteristics. Thus, it is difficult to establish standards for EM fields measurements, even different areas of the hospitals are dedicated to the same health-care activities, and similar electro-medical equipment is used (Febles et al. 2007).

This paper analyzes the signals of the different wireless communications systems in two floors of the CUHC, and presents a methodology for the generation of 2D contour maps that provide a graphical, immediate and accurate representation of the EM fields. The EM conditions have also been calculated using an assessment software.

As a possible tool, the proposed methodology can be used to assure the compliance with the exposure levels to EM fields (CR 1999), health and safety conditions in hospitals (Herranz et al. 2008) and the EM compatibility in healthcare environments. As a consequence, improvements can be performed to encourage and guarantee a better level of protection for the health and safety of workers (Karpowicz and Simunic 2009), patients, and people in general.

MATERIAL AND METHODS

Systematic measurements of the electric field have been performed on two floors of the CUHC, 9th and 10th, for four different frequencies:

- 900 MHz, the Global System for Mobile Communications (GSM) frequency band,
- 1800 MHz, the Digital Cellular Service (DCS) frequency band,
- 2.14 GHz, the Universal Mobile Telecommunications System (UMTS) frequency band,
- 2.42 GHz, the common Wi-Fi frequency.

The measurements have been carried out using a Rhode & Schwartz FSH6 spectrum analyzer and a Rhode & Schwartz HL040 log periodic antenna.

The spectrum analyzer allows measurements of the electric field, and the characterization, identification and monitoring of the signals in the environment under study. This model of the spectrum analyzer has the following characteristics:

- Frequency range: from 100 kHz to 6 GHz.
- Detection limits: –120 dBm to +20 dBm.
- Resolution bandwidth: 100 Hz to 1 MHz.

The HL040 log periodic antenna is a directive antenna that allows the identification of the radiation sources and collect data in the direction of maximum radiation. The antenna presents the following features:

- Frequency range: from 400 MHz to 3.6 GHz.
- Polarization: linear.
- Gain: 5 dBi to 7 dBi.

Fig. 1. R&S FSH6 Spectrum Analyzer and log periodic antenna in a measure scene

The measurement methodology has been proposed by CUHC and it is used for this kind of research works. The experimental measurement procedure has been performed in two areas of CUHC:

- The 9th floor, which is dedicated to surgery and neurology.
- The 10th floor, which is the unit for infectious patients and is also dedicated to digestive specialization.

These floors have been considered because they are the most exposed to the radiation sources, and are situated just below the 11^{th} floor where the radiation sources of the short range communication systems are located.

The length of each floor is 35 meters, and the values of the electric field strength have been measured in the points belonging to a predefined grid of 5 x 5 m^2, exactly in the vertices of each square that belongs to the grid. The points of measure have been selected in function of several factors: the position of the radiation sources, the location of the medical devices, the type of activities performed, etc. Figure 2 is the map of each floor obtained with AUTOCAD software where the points of measure are marked.

Fig. 2. Grid and measure points in a floor of the CUHC

The method to obtain the values is the following: in each position of measure the antenna has been oriented in order to detect the maximum value of the electric field. In this position of the antenna the value of the electric field was collected and registered.

After completing the data gathering process, the data collected were transferred to the graphic software (Surfer 10) to draw 2D contour maps according to the previously measured levels of intensity.

The EM conditions have also been calculated using an assessment software of EM fields, to provide the measurement procedure with better reliability. The simulation technique allows the prediction of the EM field in closed and outdoors environments, and avoids the drawbacks of the experimental measurements (Bui et al. 2011). Models of EM conditions reduce the cost to organize the measurement campaigns, and easily adapt for different environment setups (Kim and Lee 2009; Yun et al. 2002). A statistical treatment of both types of results, experimental and simulated, has been carried out.

EXPERIMENTAL RESULTS

The experimental measurement procedure has been performed in two areas of CUHC. The 2D contour maps of the data set, and the location of the short range radiation sources are presented graphically in Figure 3.

Fig. 3. 2D Contour maps of the experimental values of the electric field in dBuV/m.

SIMULATION RESULTS

The electric field values in different positions of two floors of the hospital have been performed with a simulation software, “EFC-400 Telecommunication”, that presents the following features:

– Ray-optical tracing method without phase information.

– 3D-calculation of power density and field strengths.

– Calculation of RMS value and peak.

– Frequency range 1 kHz to 300 GHz.

– Percentage of exposure limits frequency corrected.

– Possibility of consideration of terrain data, building data, indoor and outdoor configurations.

To start working with this software, the environment for the simulation has to be defined. It consists of the main elements that characterize the EM conditions of the considered area, such us buildings, roads, trees, bushes, furnitures, etc. The following images from the simulation software represent the environmental conditions that have been considered.

Fig. 4. Hospital environment for EM conditions.

The effect of the buildings is indicated in the configuration of the environment: a shielding effect of 15 dB has been defined.

The radiation sources have to be considered in calculating the electric field strength. Below, the main parameters of the radiation sources are indicated:

1.- The location of radiation sources must be defined in the simulation environment. For mobile phone frequencies each radiation source consists of an array of three antennas. Figure 5 shows the frequency and the position of the mobile phone antennas (IS 2010) that are situated in the surroundings of the CUHC, and Figure 6 is a map of one of the floors of the hospital where the radiation source of the Wi-Fi frequency is indicated.

2.- The radiation patterns of the radiation sources are shown in Figure 7.

3.- The gain of the antennas with respect to an isotropic radiator (dBi) are the following:

– Wi-Fi: 1 dBi

– UMTS: 18 dBi

– GSM, DCS: 15 dBi

4.- The power of the radiation sources is also configured with the following values (Ramos et al. 2005):

– Wi-Fi: 100 mW

– GSM, DCS: 40 W

– UMTS: 20 W

Fig. 5. Position of the mobile phone antennas around the hospital.

Fig. 6. Location of the radiation sources for the short range communication systems.

Fig. 7. Radiation patterns of the radiation sources.

Summarizing the aspects that must be taken into account, the steps to configure the simulation area are described as follows:

1.- Define the background map of the area and indicate the correct scale of the map.

2.- For each of the four frequencies that have been considered, the main sources of radiation must be included in the simulation environment: mobile phone antennas, Wi-Fi access point, etc.

3.- Configure the radiation sources properly, paying special attention to their different parameters such us power, frequency, and position especially if they are located on the roof of the buildings.

4.- Draw the main features of the surroundings such as, streets, roads, buildings and green areas.

Once the simulation environment has been configured, for each of the four frequencies considered, the EM conditions have been calculated taking into account the two different heights of the floors. To perform a simulation study similar to the experimental one, the peak value of the electric field is compared to the measurements obtained in the real area. Figure 8 shows the peak values for the electric field on the 9th and 10th floor.

Fig. 8. 2D contour maps of the simulated values of the electric field in dBuV/m.

DISCUSSION

A relevant point of this work is the statistical treatment of the data set. The following tables present schematically the most common statistical values of the results of the measurements made in the two identified areas of the CUHC.

Table 1. Summary of the experimental results on the 10th floor

Table 2. Summary of the experimental results on the 9th floor

Table 3. Summary of the simulation results on the 10th floor

Table 4. Summary of the simulation values on the 9th floor

After measuring and calculating the EM conditions in these areas of the hospital, it is quite important to carry out a study of the results and to check if the obtained values are under the thresholds of the recommended exposure levels (Ramos et al. 2008). The obtained EM levels are also below the security threshold stated by ICNIRP-98 (ICNIRP 1998). It means electric field levels in healthcare environments are apparently safe according with the health and safety requirements regarding the exposure of patients, staff and general public to the risks arising from electromagnetic fields.

The lower and more restrictive value of these thresholds is 3 V/m, in compliance with the International Electrotechnical Commission Standard of Electromedical Devices (IEC 2008). Examining the experimental and simulation results, the maximum value of the electric field for all the analyzed frequencies is much lower than the 3 V/m.

Other aspect that has been studied is the difference of results between both floors. As the higher floors are the most exposed to the radiation sources, the values of the 10th floor must be greater than the values of the 9th floor. This fact is true in simulated results for the short range communication systems because the radiation sources are situated on the roof of the building, nearer the higher floor.

The previously highlighted fact is not valid for the mobile phone frequencies. Regarding to the experimental results, the values of the lower floor are higher for the DCS and GSM frequencies. Analyzing the simulation results the average, maximum, and minimum values for the DCS frequencies are higher on the 9th floor. Taking into account the height of the mobile phone antennas, and the height of the two floors, the 9th floor is closer to the radiation sources than the 10^{th} floor, so the lower floor is more exposed to EM radiation than the upper floor.

Analysing the results of the UMTS frequency, the results of the experimental and simulated results are quite similar, but in the simulated results the values are higher on the 9^{th} floor, while for the experimental results the values are higher on the 10^{th} floor.

Comparing experimental values with their corresponding simulated values for each case of floor and frequency, the mean value is quite similar, but the minimum and maximum values are different. This involves a notable difference in the standard deviation, in particular the standard deviation of the experimental results is greater than standard deviation of the simulated results for the mobile phone frequencies, and lower for the Wi-Fi frequency.

For the mobile phone frequencies, the values of the electric field vary quite a lot between adjacent points in the experimental case comparing with the simulation case. The simulation environment does not always present exactly the real conditions of the areas where the measured values have been collected. There are singularities of the surroundings that are not considered in the simulation, and differences between the real and simulated source of radiations that can cause the difference between experimental and simulated results.

Analyzing the results of the Wi-Fi frequency, the standard deviation of the simulated results is greater than the standard deviation of the experimental results. It is quite probable that the CUHC is in the coverage area of another access point that is situated near the building and can affect the results of the measurements. The different features between real and simulation environment can cause different statistical behaviour of the data.

Examining the graphs, a characteristic feature of the experimental results (Figure 3) is a local peak for all the frequencies that is not present in the simulated results. This specific increase of the electric field strength matches the location of the lift and the stairs where there is a greater exposure to the EM radiation than the rest of the points of the same floor.

CONCLUSIONS

The computation of 2D contour maps of EMF in a healthcare center provides a global, immediate and accurate vision that can help to avoid EM interferences on electro medical equipment, and monitor the exposure to EM fields of the staff, the patients and the general public. This basic premise should be compatible with a sufficient signal level in wireless systems operating in a healthcare center.

The proposed procedure is useful to compare the obtained results with the thresholds of the recommended exposure levels (Bui et al. 2011), and the thresholds for the safety and basic performance of the electromedical equipment (IEC 2008). The maximum value obtained is much lower than the more restrictive threshold that is established in the International Electrotechnical Commission Standard of Electromedical Devices (IEC 2008).

EM conditions on the two floors of the hospital have also been calculated using EM field assessment software. The simulation technique allows the prediction of the EM field in closed and outdoors environments, avoiding the drawbacks of the experimental measurements (Bui et al. 2011). The calculations of EM conditions allow reducing the cost to organize the measurement campaigns, and easily adapt for different environment setups (Kim and Lee 2009; Yun et al. 2002).

In particular, the simulation of electric field strength in healthcare environments provides us with a greater knowledge of the EM conditions, and can help to discover areas with a greater level of exposure to EM radiation and areas characterized by a greater level of absorption. This fact is useful to improve the conditions and to assure a better protection for people in hospitals.

The comparison between the statistical values of the measured and simulated results helps to detect similar behaviours of the EM conditions obtained in both types of studies

As further work, the values of EM field can be collected with an omnidirectional antenna. The data set will provide more representative results about the average EM conditions in each unit of the considered hospital.

The analysis and study of the EM conditions in a healthcare environment using 2D contour maps could be helpful for the following purposes:

- To detect the over-exposed points to electromagnetic radiation and areas with greater absorption levels.
- To avoid potential harm to patients due to the interferences on electromedical equipment and on implantable personal devices.
- To achieve emission levels under of the recommended thresholds, but enough to assure a proper quality of service of wireless communication systems.
- To plan and design new high-tech healthcare centers (Hayes et al. 2008).
- To monitor properly the exposure to electromagnetic fields of health staff, patients and the general public.

ACKNOWLEDGMENT

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LIST OF FIGURE CAPTIONS

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Figure1
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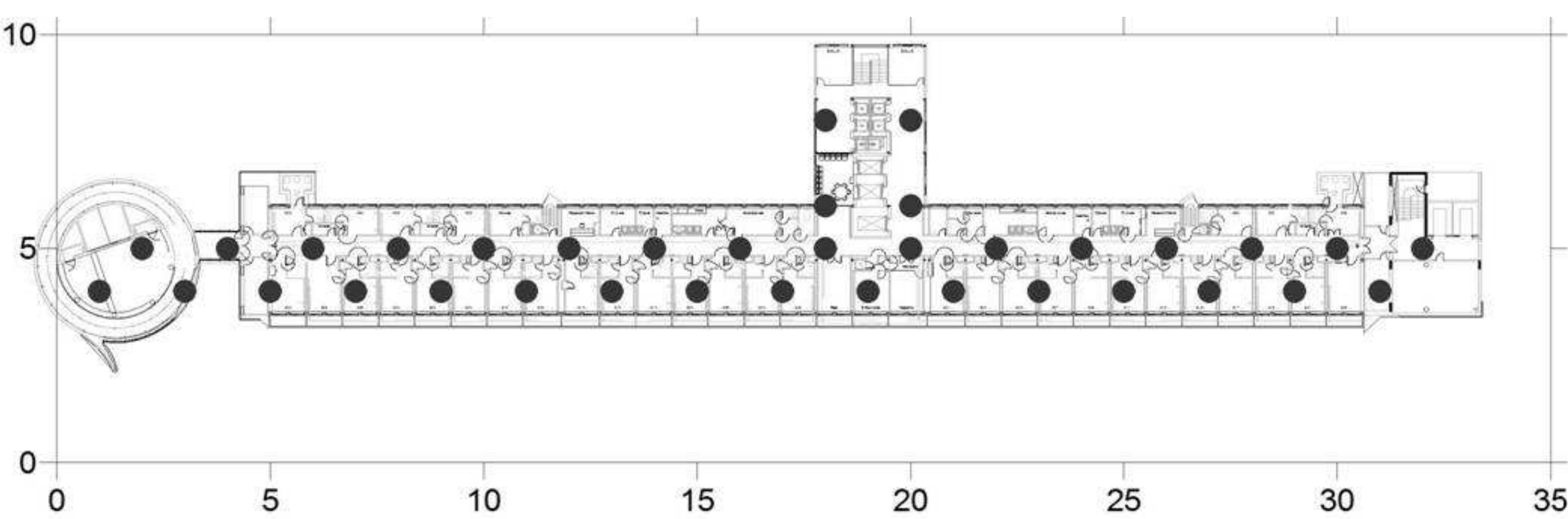
Figure2



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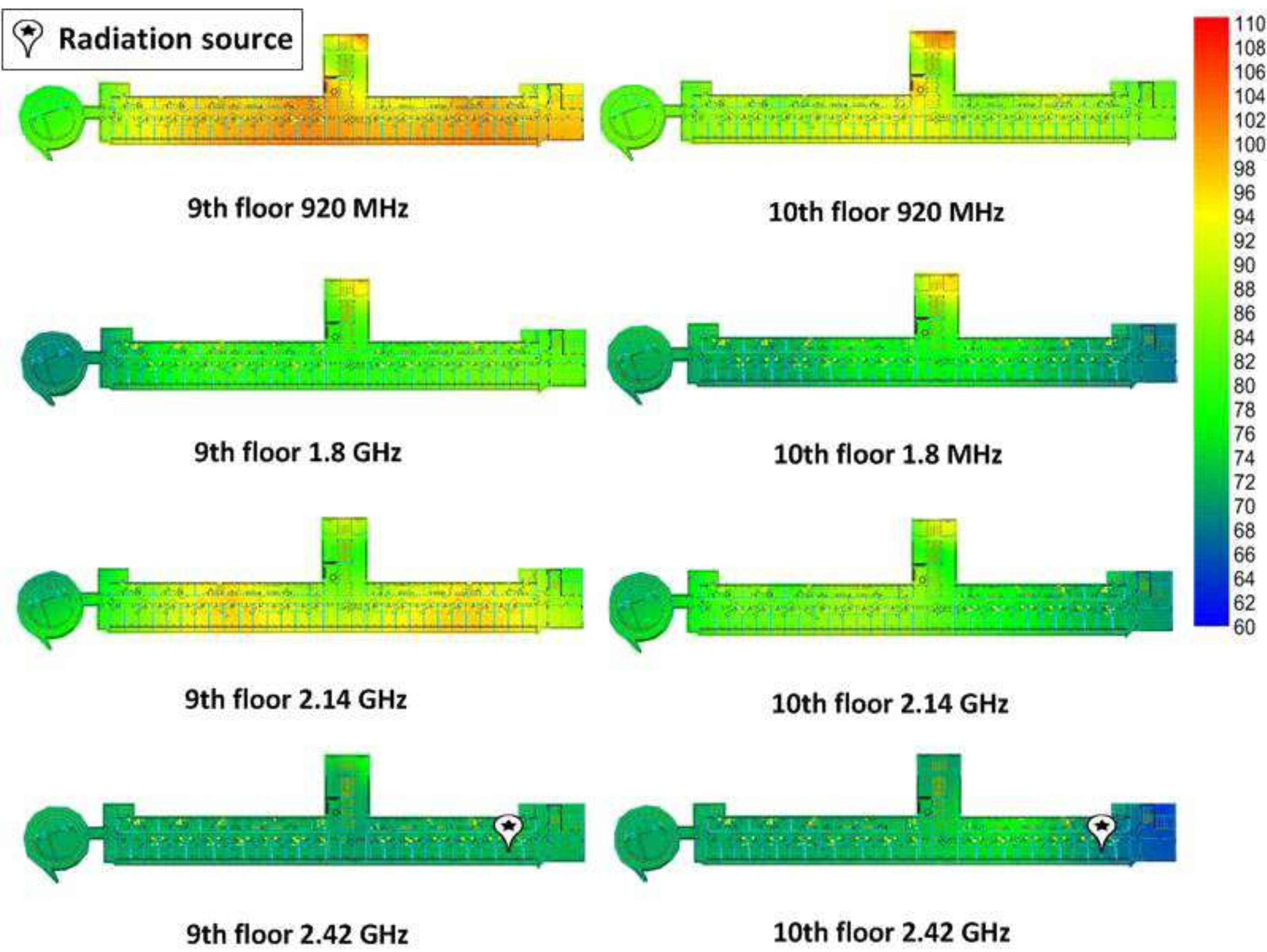

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Figure4

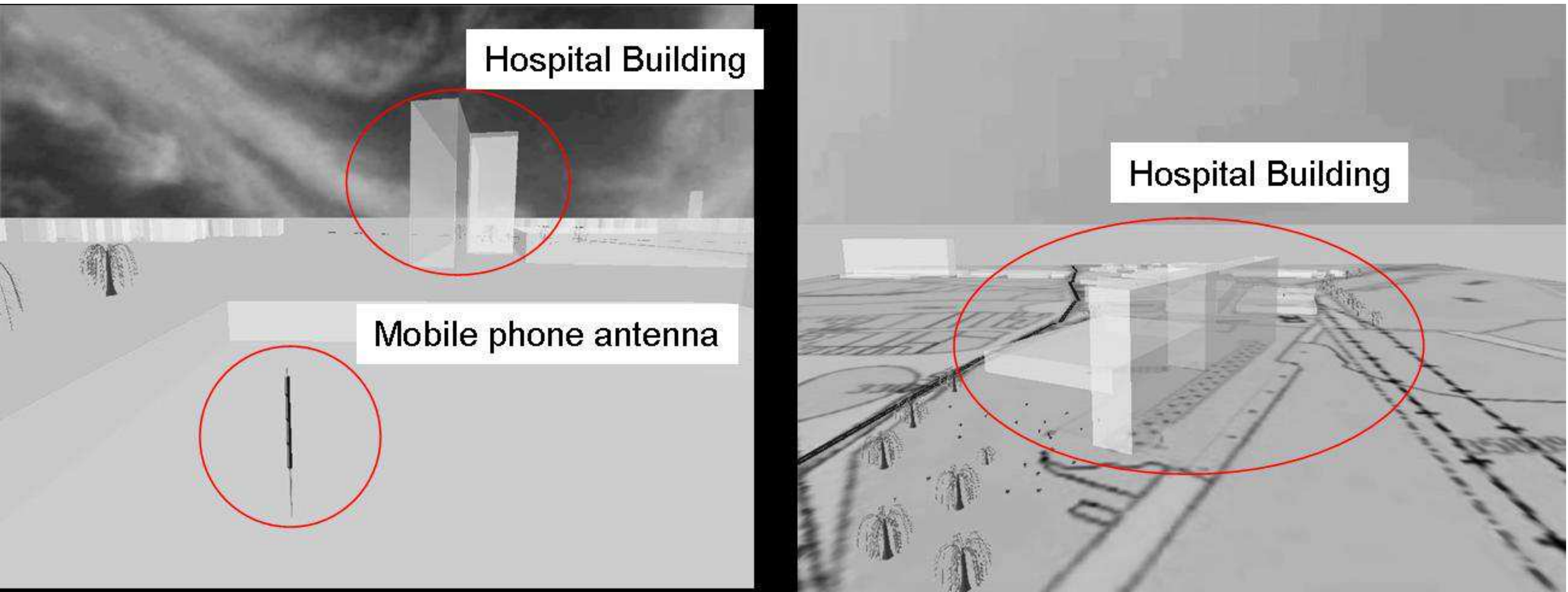
Hospital Building
Mobile phone antenna
Hospital Building

Figure5

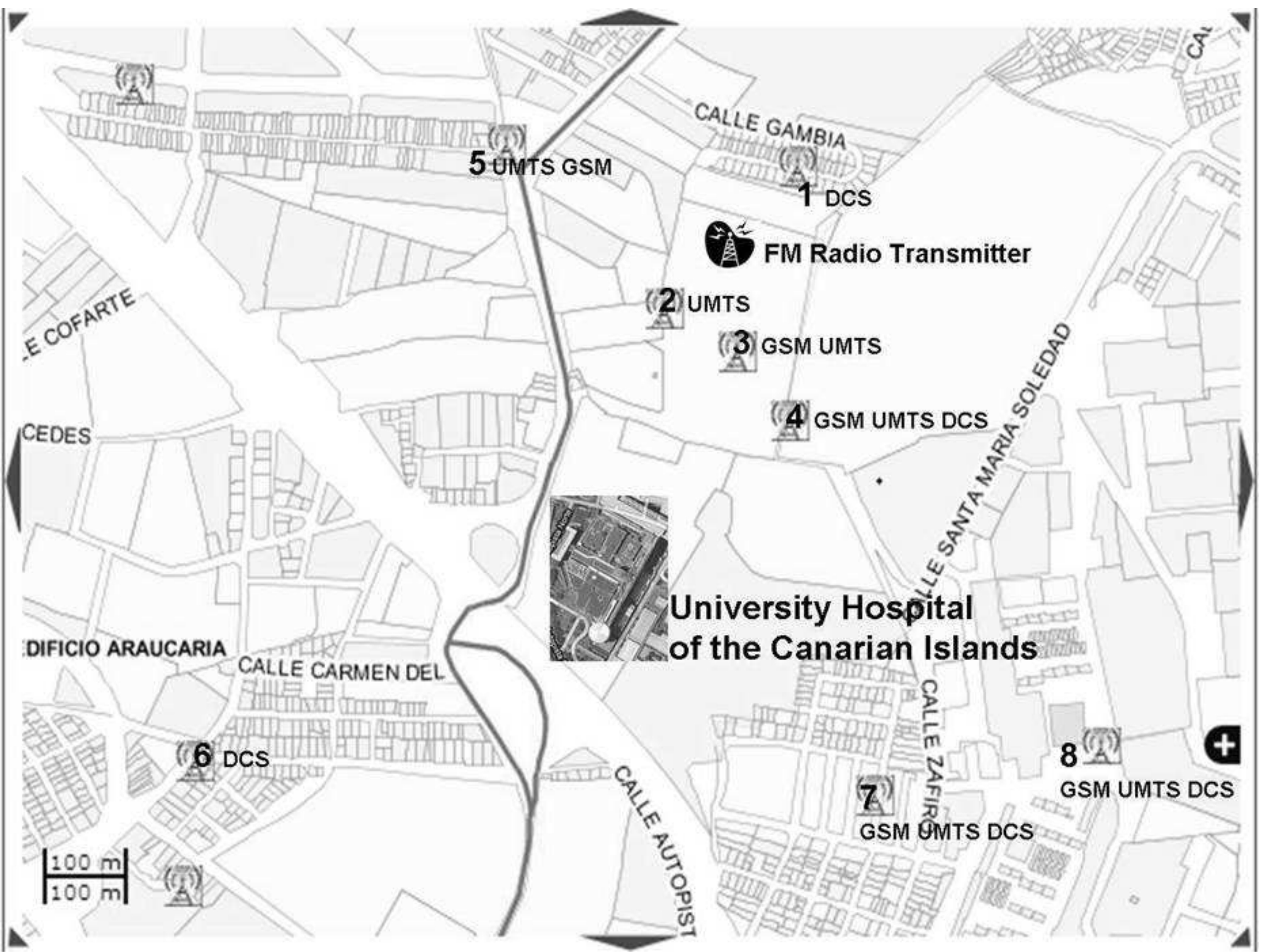

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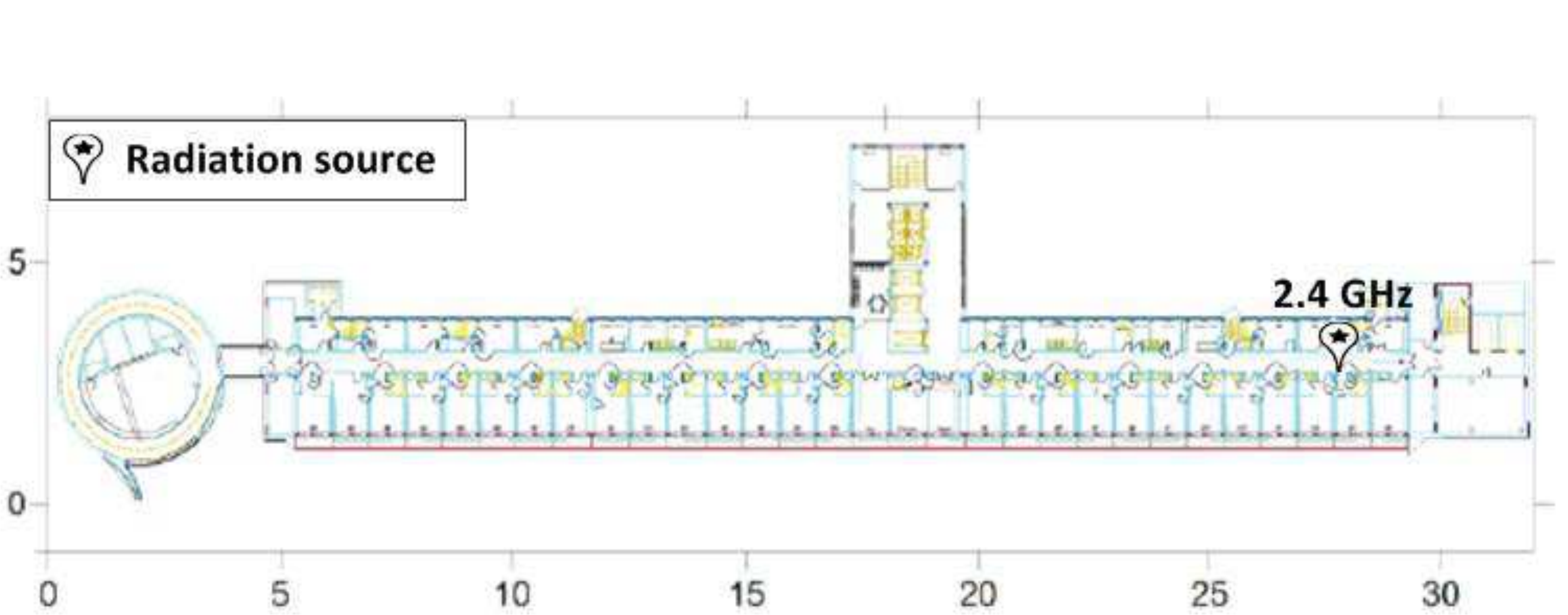
Figure6



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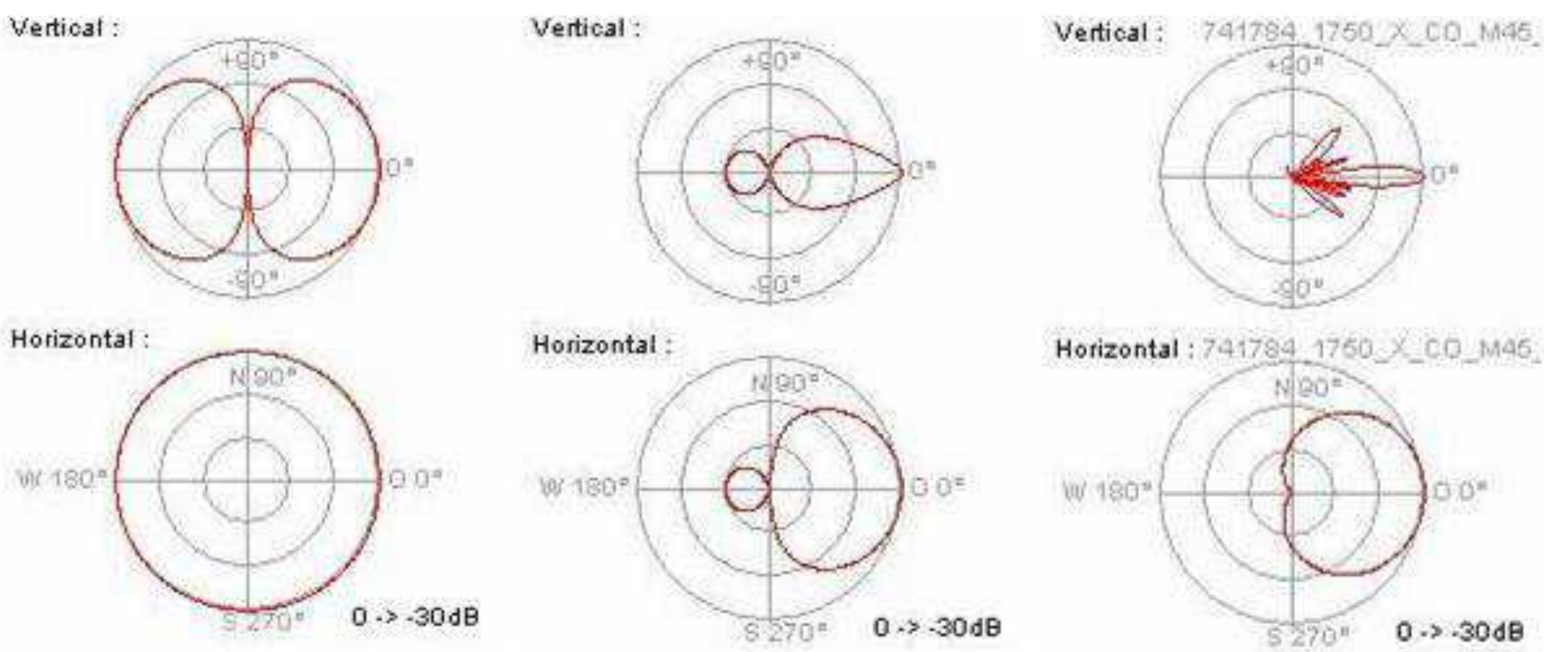
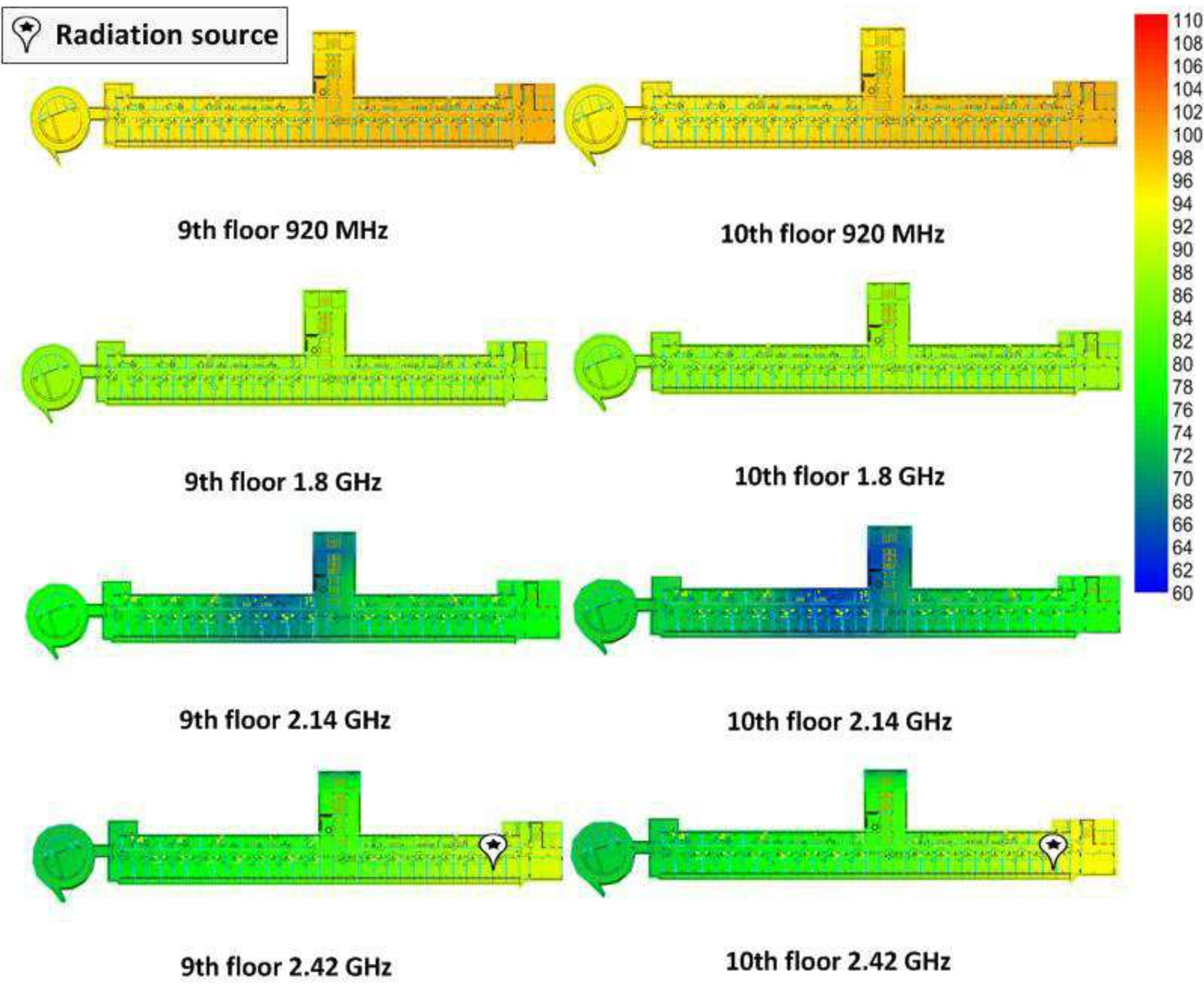


Radiation Pattern of the short range radiation sources

Radiation Pattern of the DCS radiation sources

Radiation Pattern of the UMTS radiation sources

Figure8


Radiation source
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10th floor 2.14 GHz
9th floor 2.42 GHz
10th floor 2.42 GHz

Table

Table1. Summary of the experimental results on the 10th floor

dBuV/m	920 MHz	1800 MHz	2.14 GHz	2.42 GHz
Min.	77,61	67,78	69,07	63,79
Max.	99,94	97,04	94,87	80,15
Avg.	86,96	78,17	78,31	71,42
Std.	7,65	7,92	7,70	2,75

Table

Table 2. Summary of the experimental results on the 9th floor

dBuV/m	920 MHz	1800 MHz	2.14 GHz	2.42 GHz
Min.	73,70	68,39	68,85	69,67
Max.	109,53	97,00	92,71	79,18
Avg.	89,33	79,13	80,57	72,10
Std.	9,11	7,68	7,44	2,29

Table

Table 3. Summary of the simulation results on the 10th floor

duBV/m	920 MHz	1800 MHz	2.14 GHz	2.42 GHz
Min.	94,34	85,41	63,71	64,68
Max.	98,77	87,65	79,56	93,81
Avg.	96,13	86,39	72,29	79,93
Std.	1,52	0,68	4,38	7,75

Table

Table 4. Summary of the simulation results on the 9th floor

dBuV/m	920 MHz	1800 MHz	2.14 GHz	2.42 GHz
Min.	94,45	85,93	65,73	64,48
Max.	98,93	88,30	78,52	88,95
Avg.	96,26	86,97	73,48	78,83
Std.	1,53	0,71	3,76	6,33